

A nighttime photograph of the CN Tower in Toronto, Canada. The tower is illuminated with red lights, and its observation deck is brightly lit with white lights. The background shows the city skyline with various skyscrapers and buildings, some of which are also illuminated. The sky is a deep blue.

# LED Essentials

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Chair, NEMA Sub-Committee on Solid-State Lighting

Department of Energy  
Webinar Oct 11, 2007

# Tubes To Transistors All Over Again

## Analog

Vacuum tube

LP records

Film

Rotary phone

VHS

Linkages

Typewriter

## Digital

Transistor

CDs → mp3

CCD

Cell phone

DVD

'Fly by wire'

Computer



Lighting is the last refuge of analog

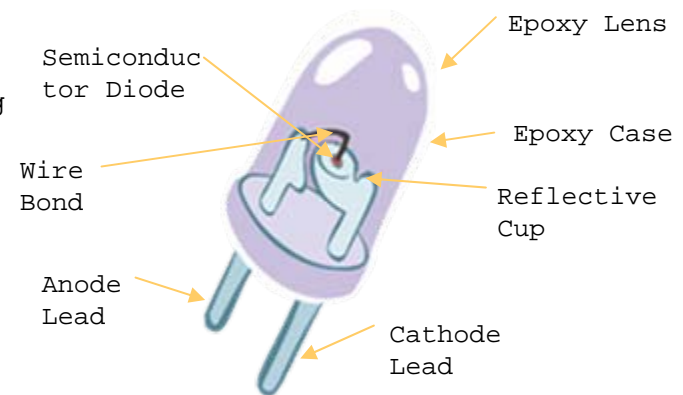
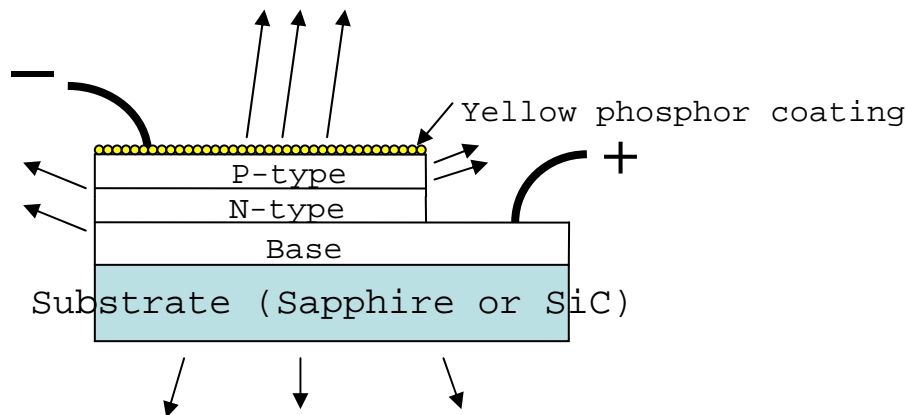
# A Brief LED History

- 1962 First LED (Holonyak at GE)
  - 0.001 lumens
- 1960's Red LEDs (HP & Monsanto)
  - 0.01 lumens
- 1970's–1980's Green LEDs, Watches, Calculators
  - 0.1 lumens
- 1990's Blue LEDs (Nakamura at Nichia)
  - 1 lumen
- 2000+
  - 10-100 lumens
- 2005
  - 1000 lumens (multichip packages)
- General Illumination



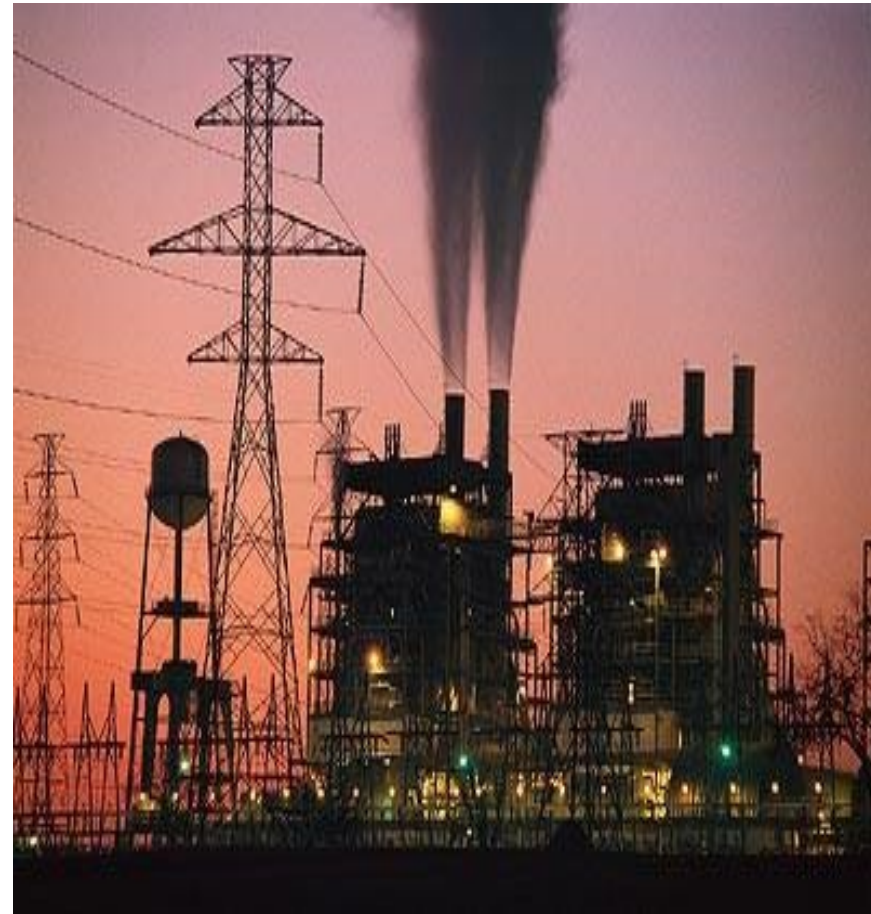
# LED Background

- A semiconductor device that converts electrical energy directly into a discrete color of light
- Made from compound materials
- Made in chip fabrication factories
- Not brass, glass and gas
- White LEDs are blue LEDs + phosphor



# Lighting Industry Facts

- Lighting is \$70 B Globally
- Lighting is over 20% of electricity use
- Lighting energy costs \$40B/yr
- LED Lighting could reduce lighting energy 50% by 2025
- Savings from 2000 to 2020 could
  - Eliminate need for >100 1000MW power plants
  - Save over \$100B



# Solid State Lighting Facts

- Example: Traffic Lights
  - The cost to run an incandescent traffic light is \$16/year
  - The cost to run an LED traffic light is \$2/year
  - Replacing US traffic signals could save \$200M/year



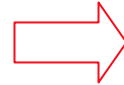
# From Indication to Illumination

- Monochrome Indicators
  - Traffic lights, automotive, exit signs etc
  - Portable appliances, cell phones & PDAs
  - Signage
  - Direct view displays; video screens
- Emerging Applications
  - Transportation: marine, auto, aviation etc.
  - Lighting niches
- Near Future
  - General Illumination



# Lighting Sources

## Conventional Lighting Sources



## SSL Source

- Incandescent



- Halogen



- Fluorescent



- Gas-discharge  
(example: neon)



- Light emitting diodes (LEDs)



### Benefits of SSL

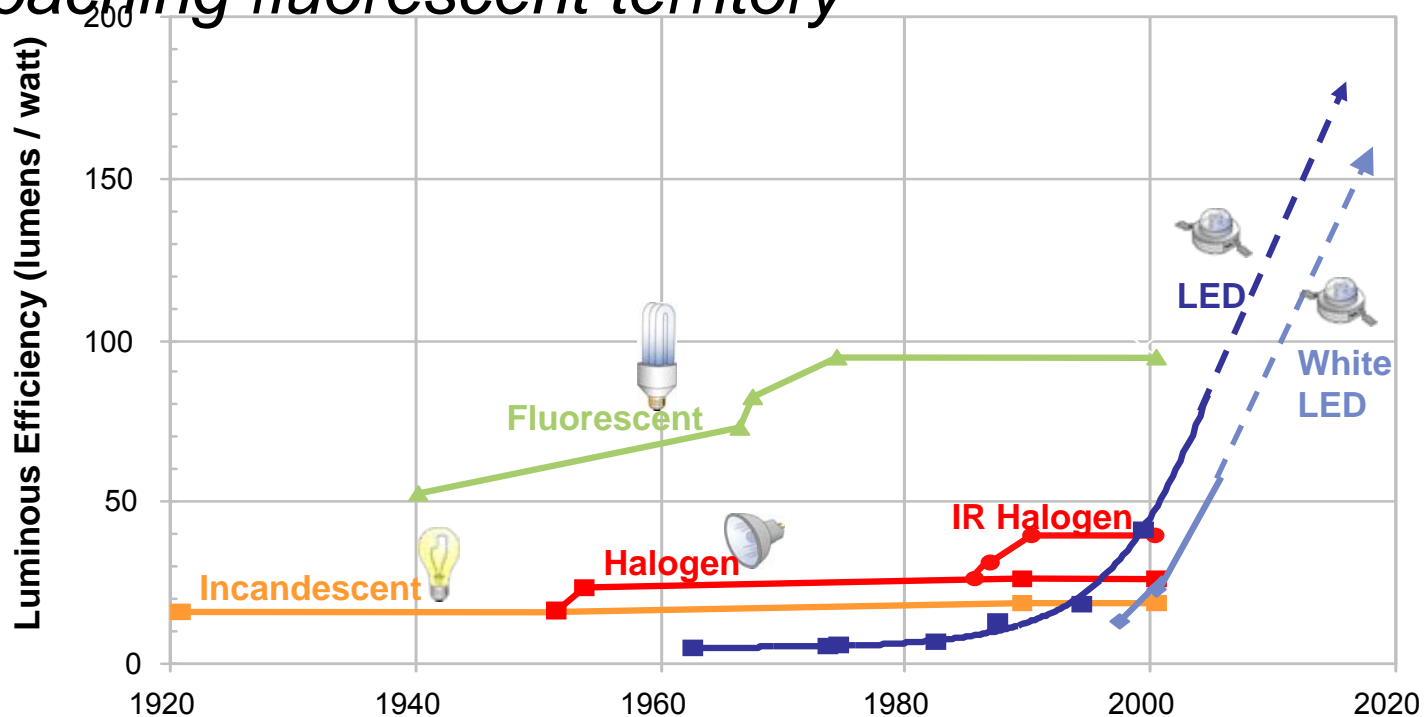
- Ultra long source life
- Low power consumption
- Low maintenance
- No moving parts
- Vibration resistance
- No UV radiation
- Cool beam of light
- Digitally controllable
- Fast Response

# LED Source Life

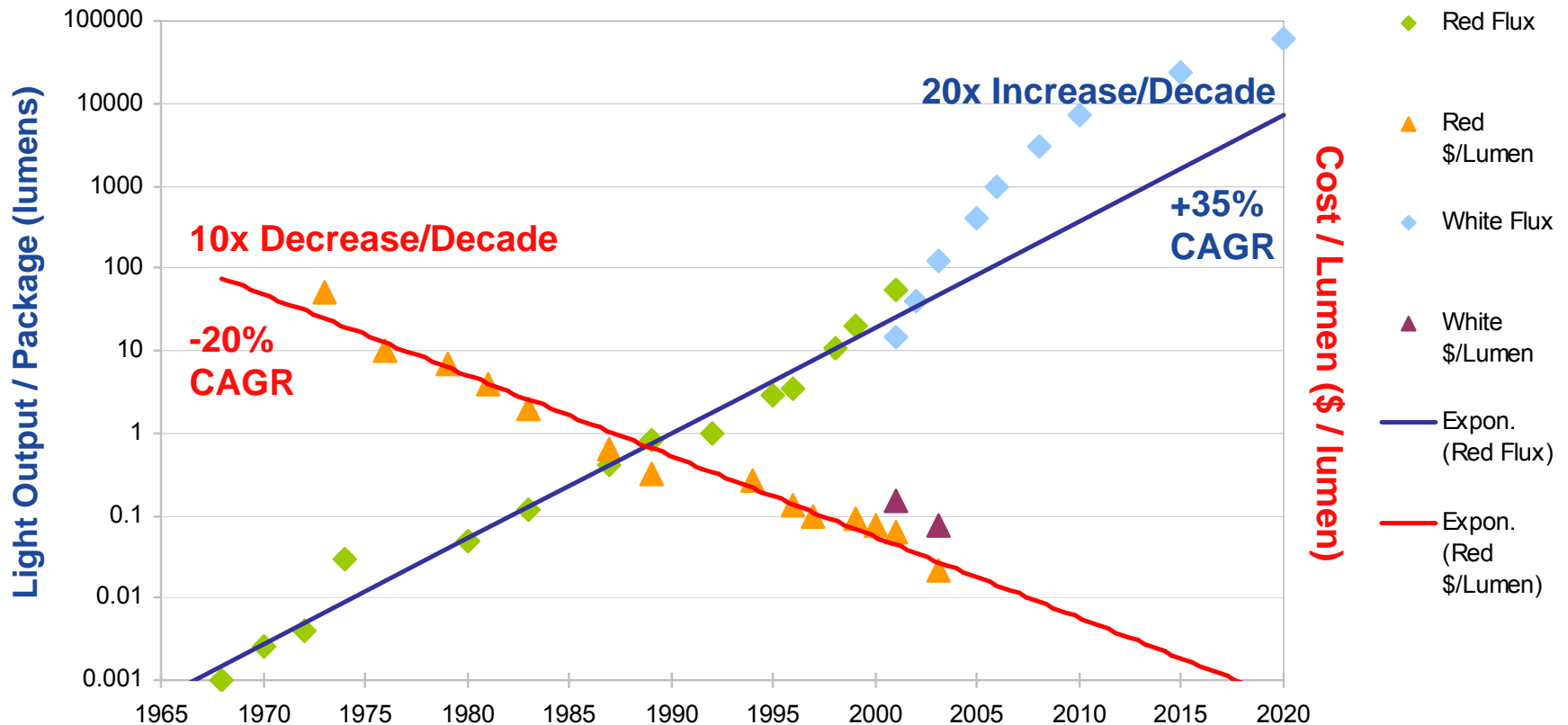
- Lifetime Definition
  - Traditional lighting: Average time to failure
  - LEDs: Time to 70%/50% lumen depreciation
    - Fluorescent 25% down over their lifetime
    - Incandescent down 15-20% over their lifetime
  - Predicted LED source life between 50-100K hours
    - Your mileage may vary
    - 50K to 75K typical for high-flux packages

# Light and Power

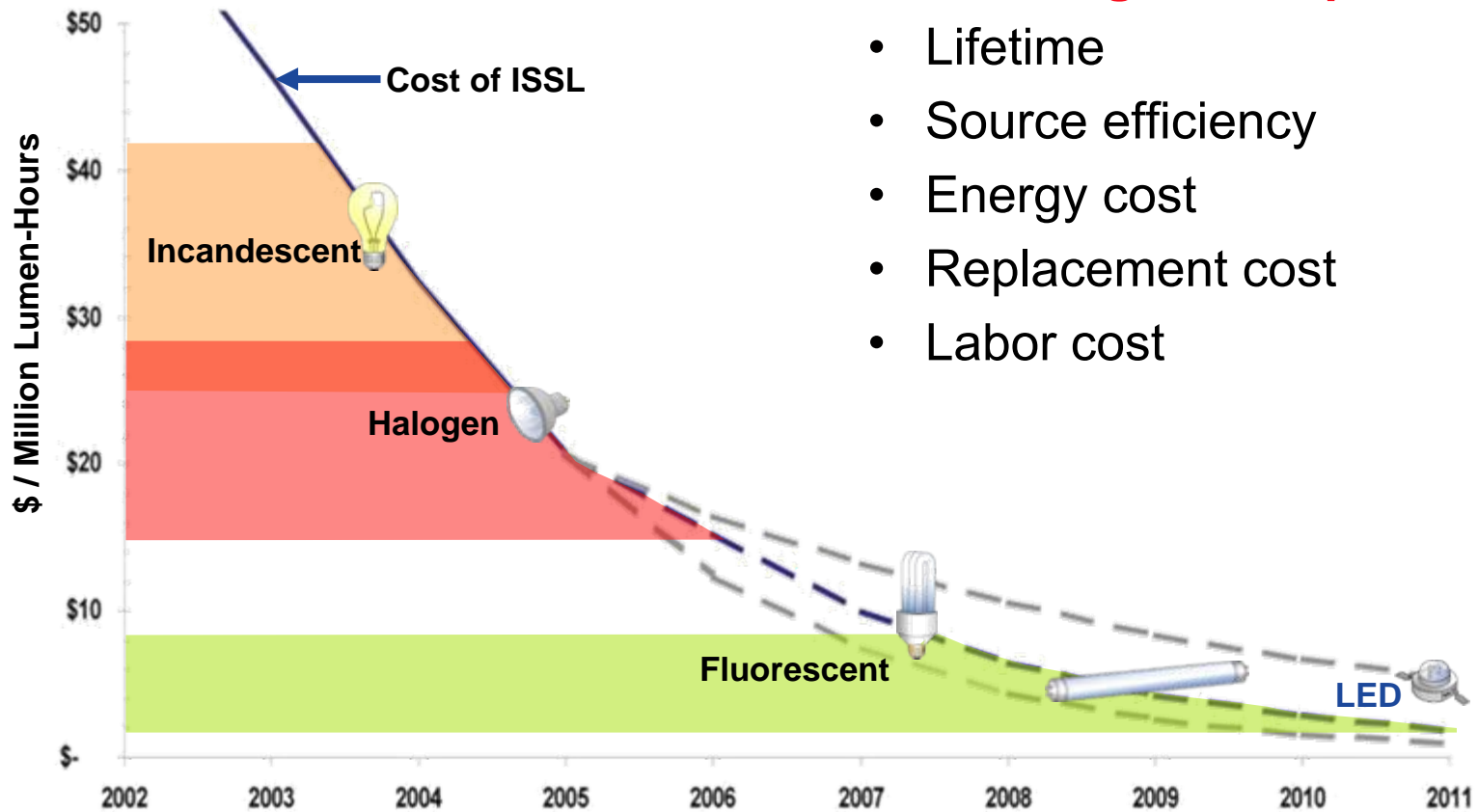
*The efficiency of LED sources is eclipsing that of incandescent and halogen sources and fast approaching fluorescent territory*



# LED Output and Cost Trends



# The Cost of Light



## Cost of Light Incorporates:

- Lifetime
- Source efficiency
- Energy cost
- Replacement cost
- Labor cost

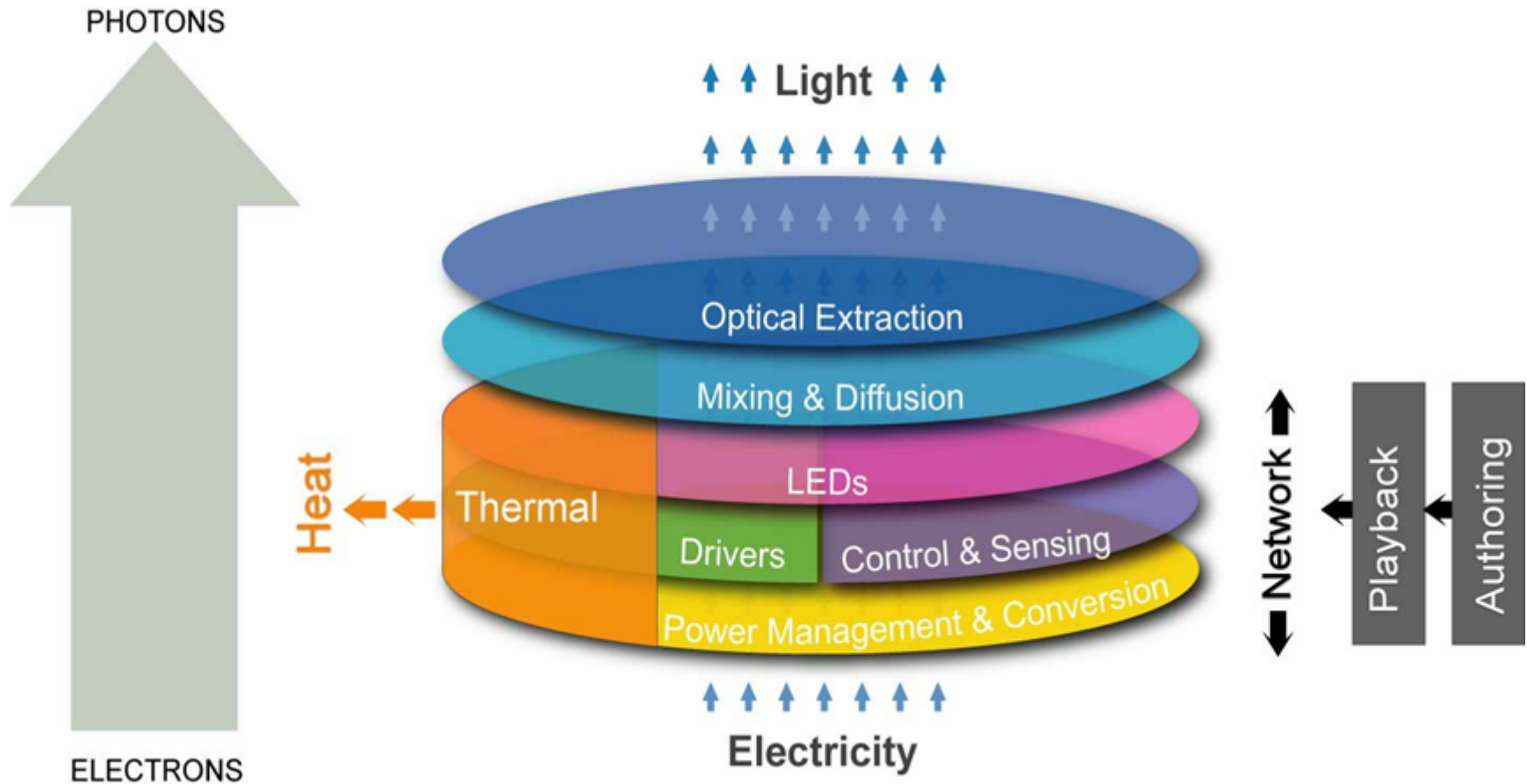
# Energy Conservation

*The efficiency of solid-state sources is eclipsing that of incandescent and halogen sources*

- The Cost of Light is not simply the up-front cost
- Industry Cost of Light criteria
  - Energy costs
  - Power consumption
  - Labor costs
  - Lamp costs
  - Lifetime
  - Light output

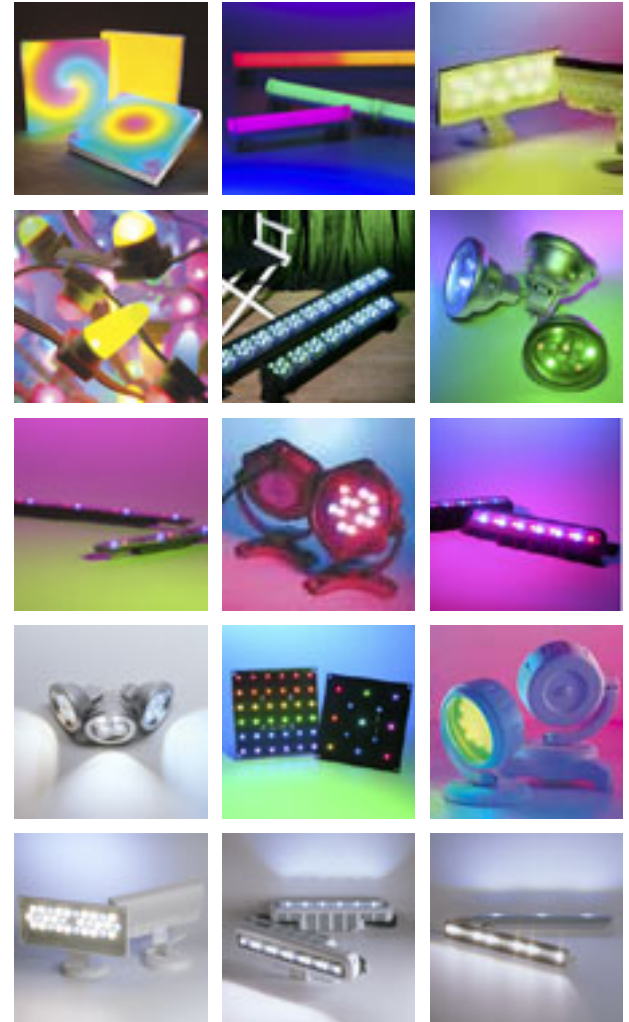


# An LED System



# Complete Lighting Systems

- Fixtures are available for many applications including architectural, hospitality and much more
- Effects-based lighting is networked and easily controllable
- General white LED Illumination solutions are becoming available



# White Light LED Systems

- Advanced high-brightness white LEDs with digital control expertise
- Color temperature controllable with warm white and cool white LEDs
- Fixed color dimmable products allow the adjustment of light intensity using standard low voltage dimmers



# White Light LED Systems

- Light from the sun changes color throughout the day
- You already can choose from many colors of white in fabrics, surfaces, paint, carpets and more.
- Why not have a choice in white light?



# Light Output at Three Different Color Temperatures



# Effect of Color Temperature on An Object



3000 Kelvin

3500 Kelvin

6500 Kelvin

# Trends

## Good trends in LED Lighting

- Increased awareness by end-users
- Increased specification of LED lighting systems
- Increased market growth in LED Lighting

## Bad trends in LED Lighting

- Specifications of LED systems from devices to fixtures is misleading

# A Real Danger: Hyperbole

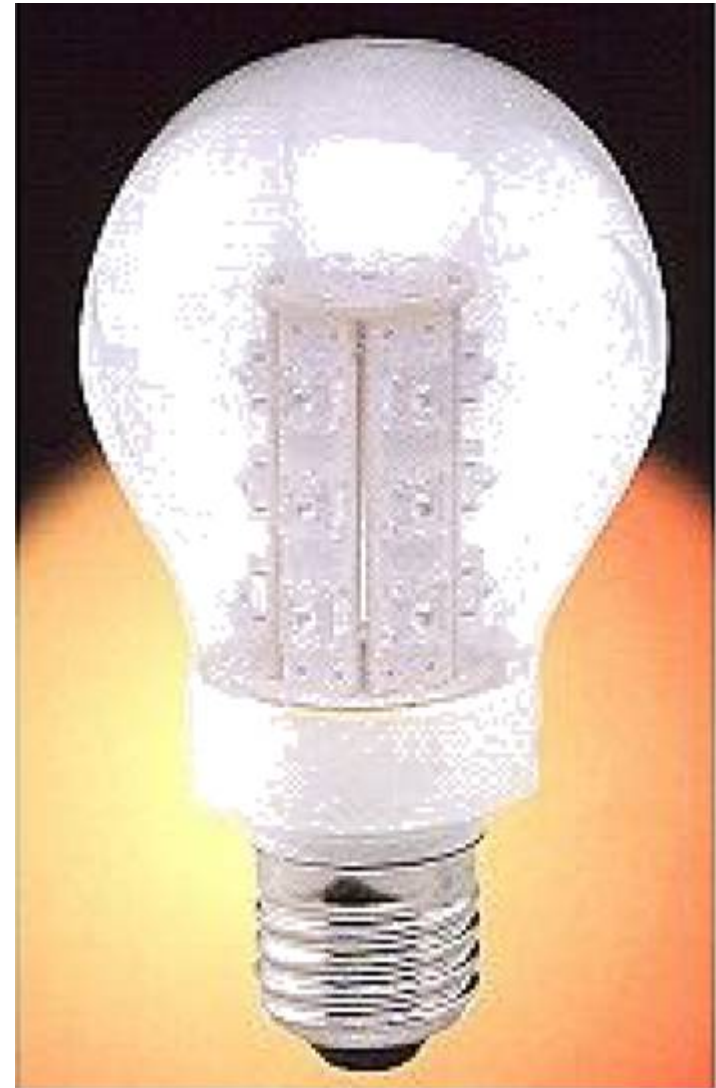
“Uses almost no energy!”

“Lasts Forever!”

Nothing will kill an industry faster than expectations that cannot be met.

Performance must be realistic and factual.

Costs must be complete.



Wow! Uh, Wait a second...

**X** announces LED **86** lumens per Watt - 9/2/2005

**Y** develops **100** lm/W white LED chip - 3/13/2006

**X** white LED produces **131** lm/W - 6/20/2006

**Z** New Record in Efficient LEDs. **116** lm/W - 12/18/2006

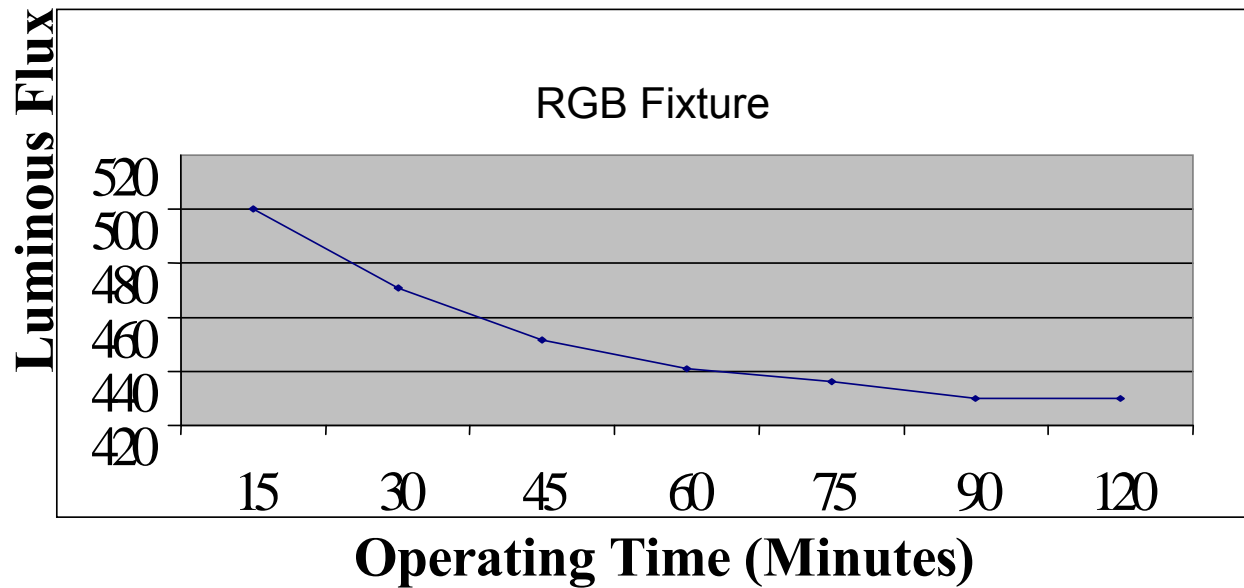
**X** achieved **150** lm/W white LED Lamps - 12/21/2006

# Measuring Output

- Sum of the parts does not equal the whole
- Sum of lumens on individual LEDs does **not** equal the total output of the fixture
- Thermal issues affect measurements
- Whole fixture must be measured to standard
- Standards in the works for measuring fixtures



# Heat and Light



# A Different Story - DoE Product Testing

Table 1. Pilot Round Test Partial Results <sup>1</sup>				
Photometrics based on LM-79 for <ul style="list-style-type: none"> <li>• Complete luminaires</li> <li>• 25° C ambient temperature</li> </ul>	Light Output (lumens)	Luminaire Efficacy (lm/W)	Correlated Color Temperature (K)	Color Rendering Index
<b>CPTP 06-01 Downlight<sup>2</sup></b> (manufacturer published LED luminous efficacy = 40 lm/W)	193	12.82	3012	70
<b>CPTP 06-02 Under-cabinet Light</b> (manufacturer published LED luminous efficacy = 55 lm/W)	166	16.07	<i>See note<sup>3</sup></i>	
<b>CPTP 06-03 Downlight</b> (manufacturer published LED luminous efficacy = 45 lm/W)	298	19.3	2724	67.3
<b>CPTP 06-04 Task Light</b> (manufacturer published LED luminous efficacy = 36 lm/W)	114	11.6	<i>See note<sup>3</sup></i>	

# Why LED Standards Now?

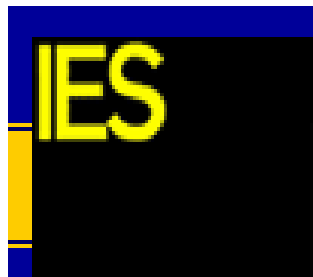
Industry and SSL customers need

- Uniform language & definitions
- Uniform test methods
- Laboratory accreditation

# Types of Standards

- Safety
  - Shock and fire hazard
- Performance
  - Measured Criteria
- Architecture and Form
  - Mechanical/Thermal Interfaces
  - Electrical Interfaces
  - Communications & Controls Interfaces
  - The Light

# Who is Involved in Standards Development?



# Safety Standards

- Now using best practices and existing listing standards
- New UL Standard, 8750, In Development
- Standards Technical Panel (STP) established



# LED Performance Standards Activity

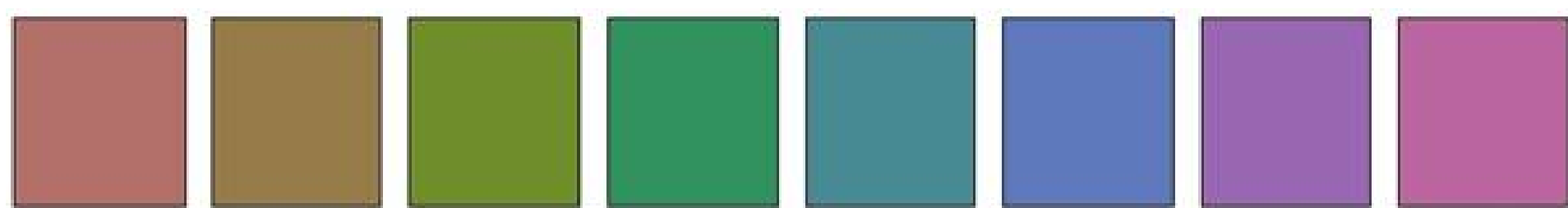
- Chromaticity
- Luminous Flux
- Lumen Depreciation
- SSL Definitions
- Photobiological Safety
- Drivers
- Safety
- Color Quality Index



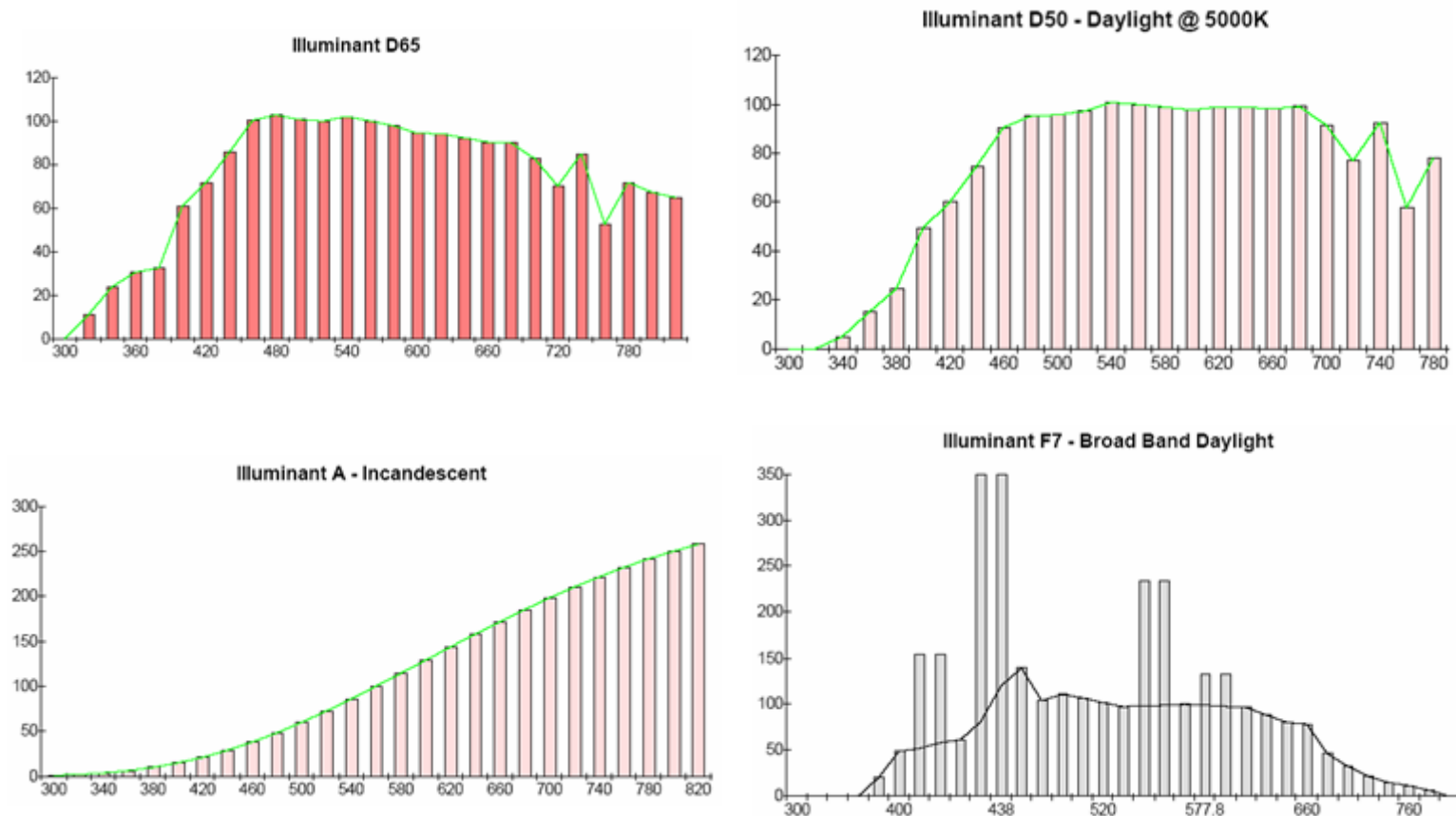
# Issues with Color Rendering Index (CRI)

- Uses obsolete color space
- Samples are low saturation
- Outdated adaptation formula
- Poor in red region

Updates are being proposed



# Same CRI numbers are **not** Equivalent!



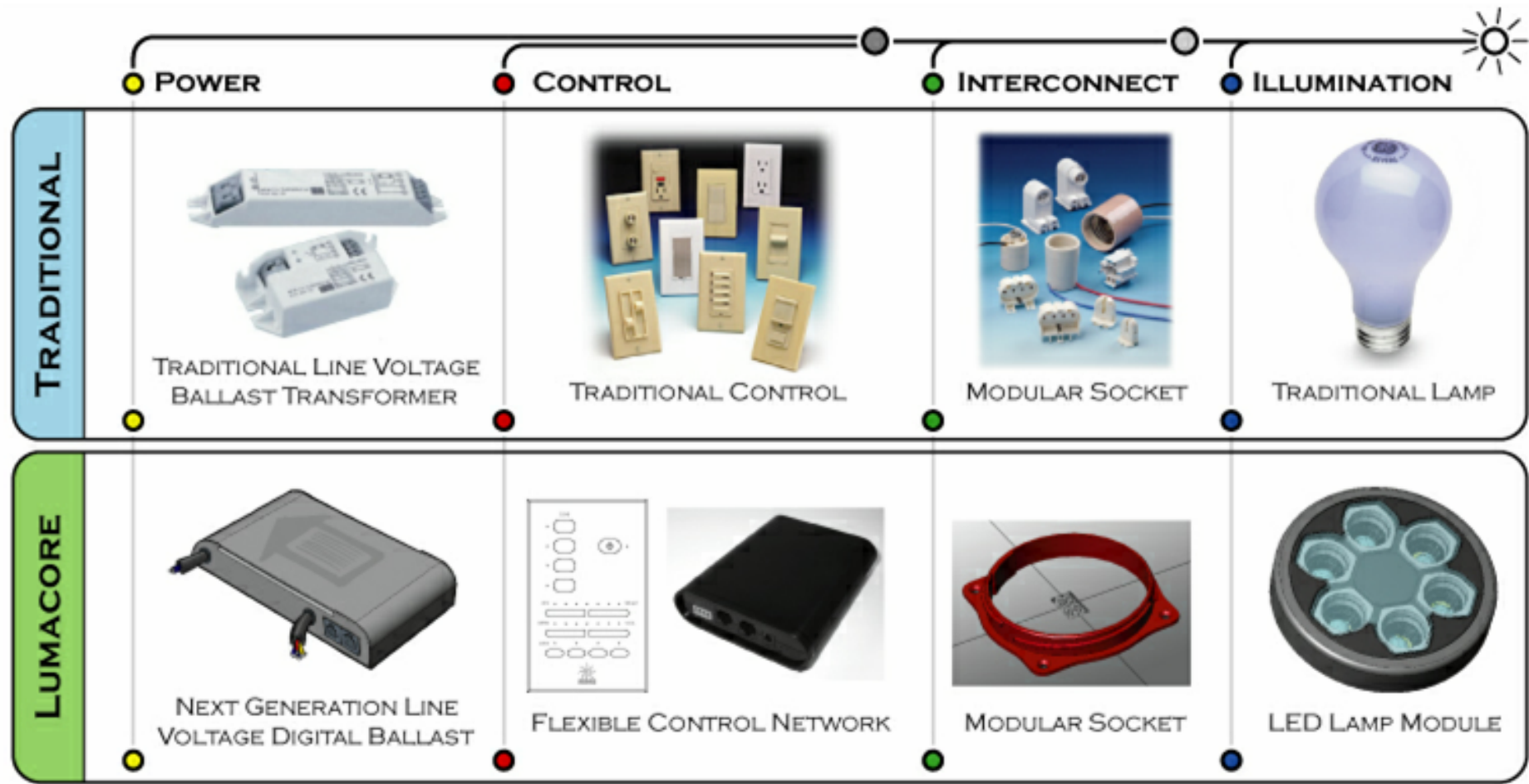
Clearly different but all of these CRIs are 100!

# CRI is Misleading

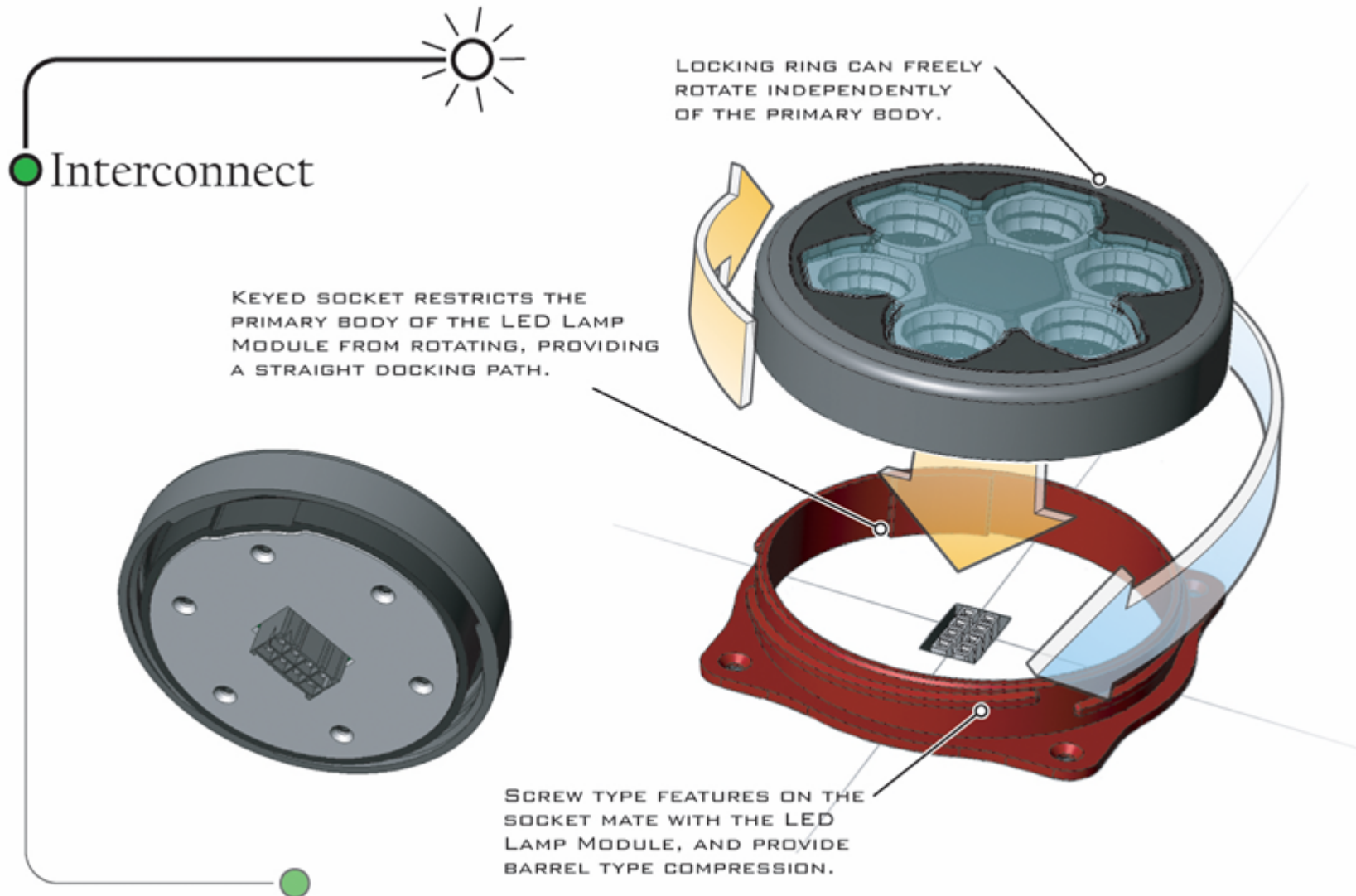
- Incandescent source CRI is 100
- But light does not render all colors well
- Try matching dark Navy Blue & Black socks under a low or medium luminance incandescent light!



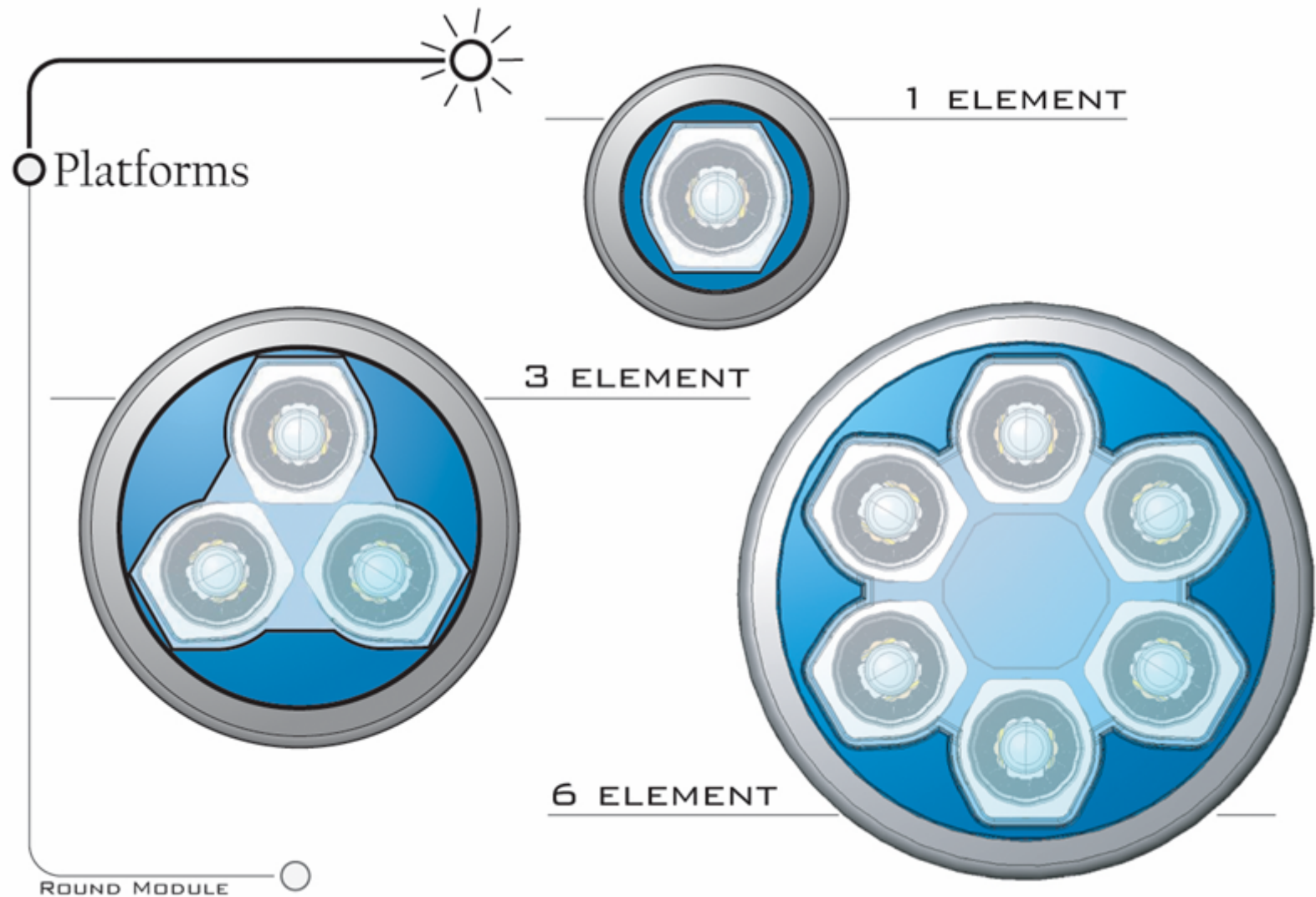
# LED Lighting Systems



# Anatomy Of A Next Gen LED Lighting System



# Replacement LED Lamps?



# LED Progress Continues

- Output continues to climb
- Efficiencies continue to improve
  - Probably eclipsing fluorescents
- Light quality improving
- Standards under rapid development
- Costs coming down
  - Energy savings are real

# Regulations and Compliance

# Legislation and LEDs

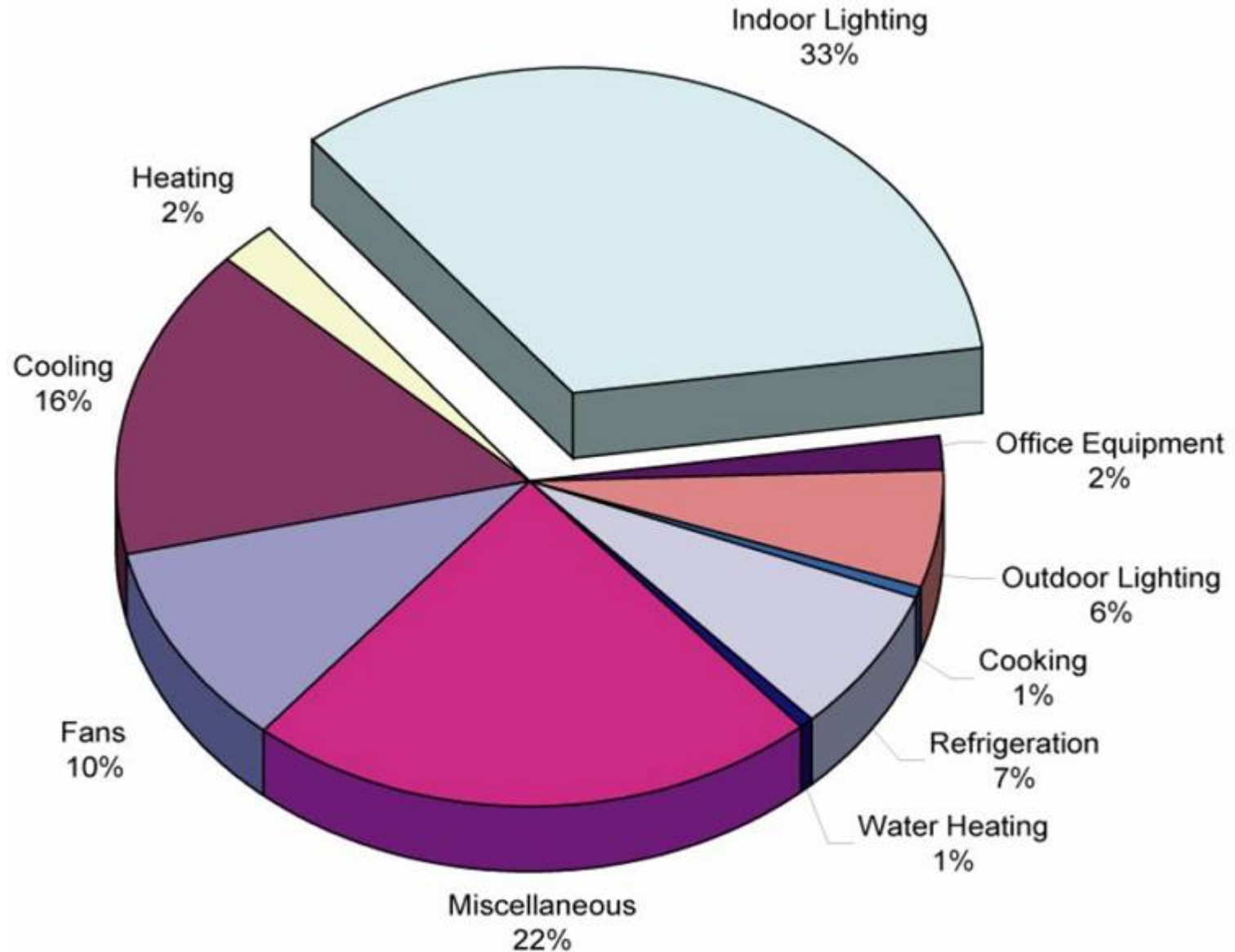
- California Title 24
- LEED
- Energy Star

## Others

- ASHRAE 90.1
- RoHS/WEEE

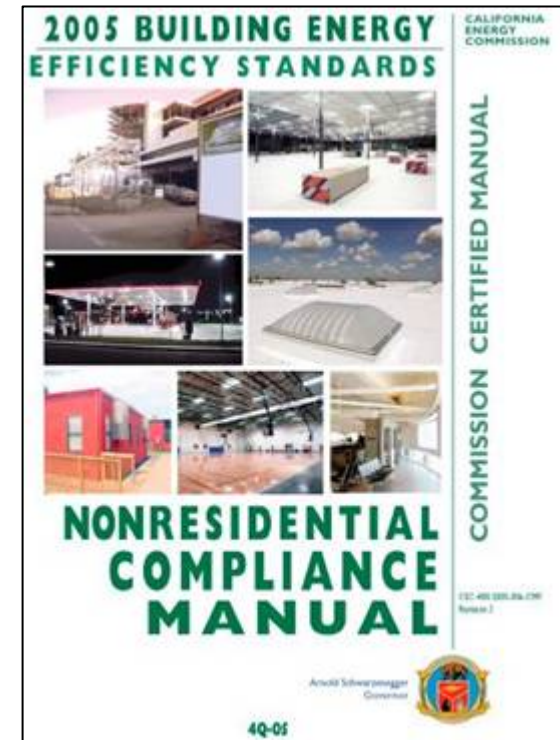


# Why Title 24?



# Title 24

- California's Energy Efficiency Standards for Residential and Nonresidential Buildings
- Currently using 2005 standards, but 2008 in draft form. Lighting in sections 5-6
- Primary means for reducing energy use is to limit allowable lighting power in a building
- <http://www.energy.ca.gov/title24/>



# Title 24

- Allowed Lighting Power Methods
  - Complete Building Method
    - Single function use
  - Area Category Method
    - Lighting power values assigned to each function area (e.g. offices, lobbies, corridors etc)
  - Tailored Method
    - Accommodates specific task areas
  - Performance Approach
    - CA CEC Programs are used
    - Special permits

# Title 24

- Lighting Controls
  - Minimum features for time switches, occupant-sensing devices, automatic daylighting control, photosensors and more
  - Table 5-8 in T-24 allows for lighting power adjustment factors using controls and sensing such as dimming, daylighting and other sensing

# LEED

- LED-based lighting falls under the lighting category for LEED
- There are a number of areas within lighting and control that enable several potential LEED points.

# Energy Star

- US program to promote energy efficient products
- LED Lighting version in the works
- Near Final draft now available
- <http://www.energystar.gov/>



# Energy Star

- **Category A - Near Term Niche Applications**
  - **Under cabinet Kitchen Lighting (23 lpw, CRI 80)**
  - **Under cabinet shelf-mounted task lighting (29lpw, CRI 80)**
  - Portable desk task lights (29lpw, CRI 80)
  - Outdoor wall-mounted porch lights (27 lpw, CRI 70)
  - Outdoor step lights (23 lpw, CRI 70)
  - Outdoor pathway lights (29lpw, CRI 70)
  - **Recessed Downlights (Res 29 lpw CRI 80, Comm 33lpw, CRI 70)**
- **Category B - Efficacy Based Performance**
  - CCT <3000K >50lpw
  - 3000K < CCT < 5000K >60lpw
  - CCT > 5000K >70lpw
  - CRI indoor >80, Outdoor >70

# Energy Star Criteria

- Luminous Flux
- Power & Power Factor
- Efficacy
- Lifetime
- CRI
- Distribution

# Chromaticity

- ANSI C78.377A
- Defines Color Temperature regions
- Reviewed comments - going to ballot now.
- Spin-off effort killed. Thank goodness.
- Already being adopted by LED mfgs (Cree)

# Light Output

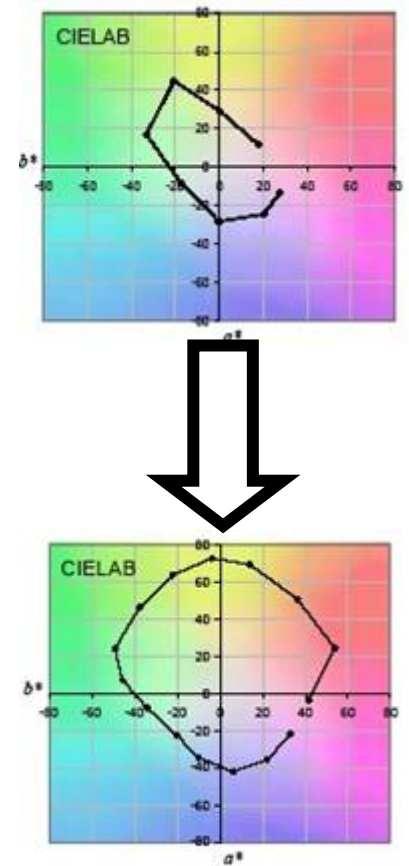
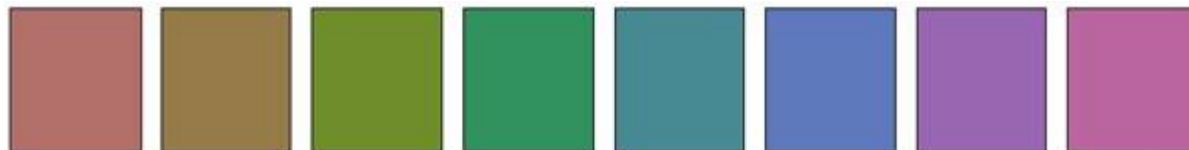
- IESNA LM-79
- Comment Period 09/05 - 10/10/06
- Sent to IES/ANSI Committee in Fall 2006
- Draft 5.0 - Now out for committee review
- Reviews

# Lumen Depreciation

- IESNA LM-80
- Determine LED Lifetime,  $L_{70}$ ,  $L_{50}$
- Draft 2.0: Dec 7, 2006
- Comments through 6/28/07

# CRI

- Uses obsolete color space
- Samples are low saturation
- Outdated adaptation formula
- Non-linear in red region
- Adversely affects LED scores



# Summary

- Tracking and Supporting Legislative activities
- Pushing hard on Energy Star and Standards activities
- Supporting materials available
  
- CK is ready!
- Thank you.

# Showcase

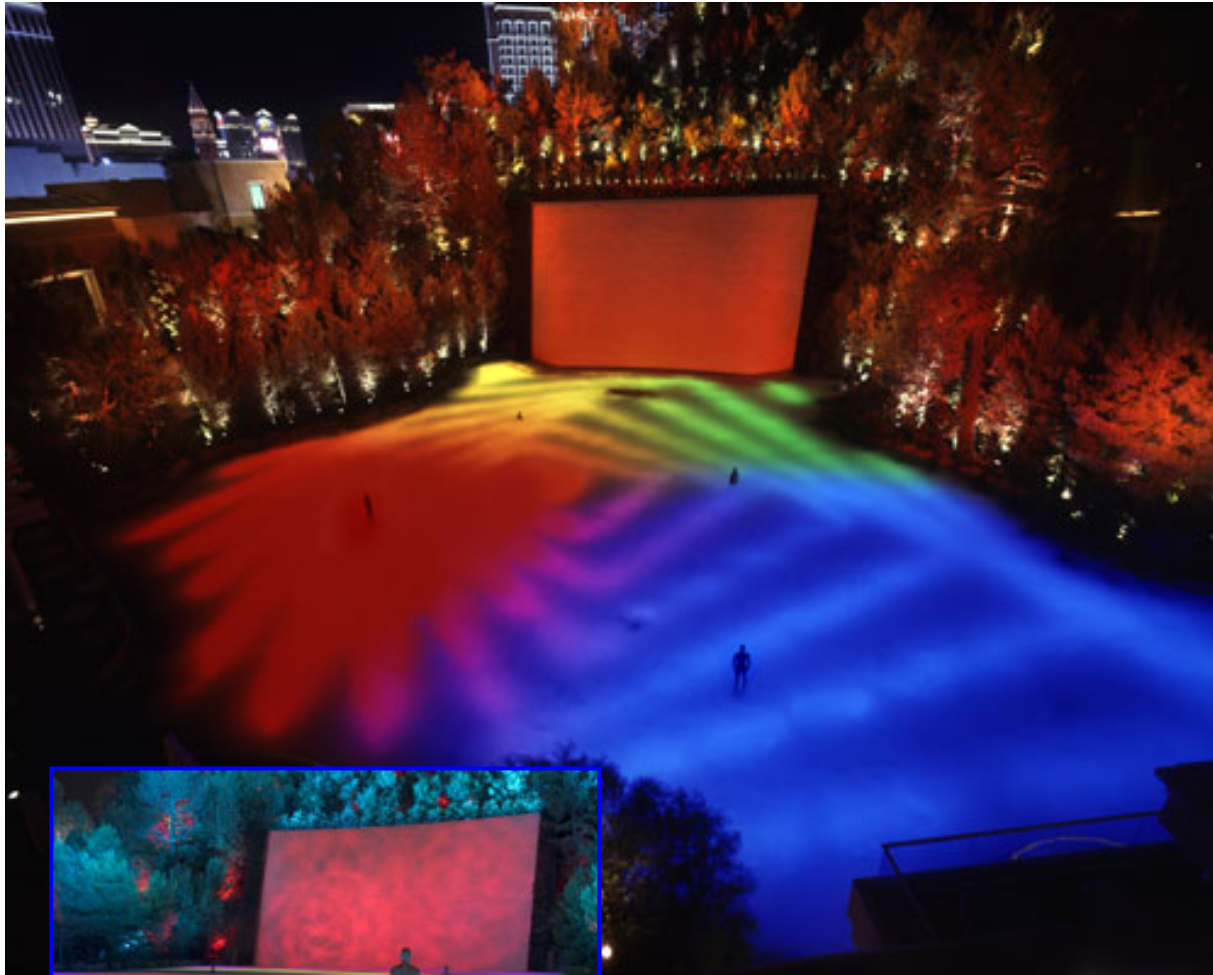
# Hollywood Bowl

Hollywood, CA, USA



# Wynn Las Vegas

Las Vegas, NV



Retail

# FAO Schwarz

New York, NY



# Lacoste Boutiques

Multiple US Locations



# Cartier

Paris, France



# Reebok

Antwerp, Belgium



Hospitality

# Quo

New York, NY



# Bryant Park Hotel

New York, NY



# Morimoto Restaurant

Philadelphia, PA



# W Hotel

Walkerhill, Seoul, Korea



# Dorsia Lounge

New York, NY



Residential

# Orange County Residence

Santa Ana, CA



# Creative Home Theater

Las Vegas, NV



# Mexico City Residence

Mexico City, Mexico



# Installation Art

# Traveling Light by Peter Freeman

Bristol, UK

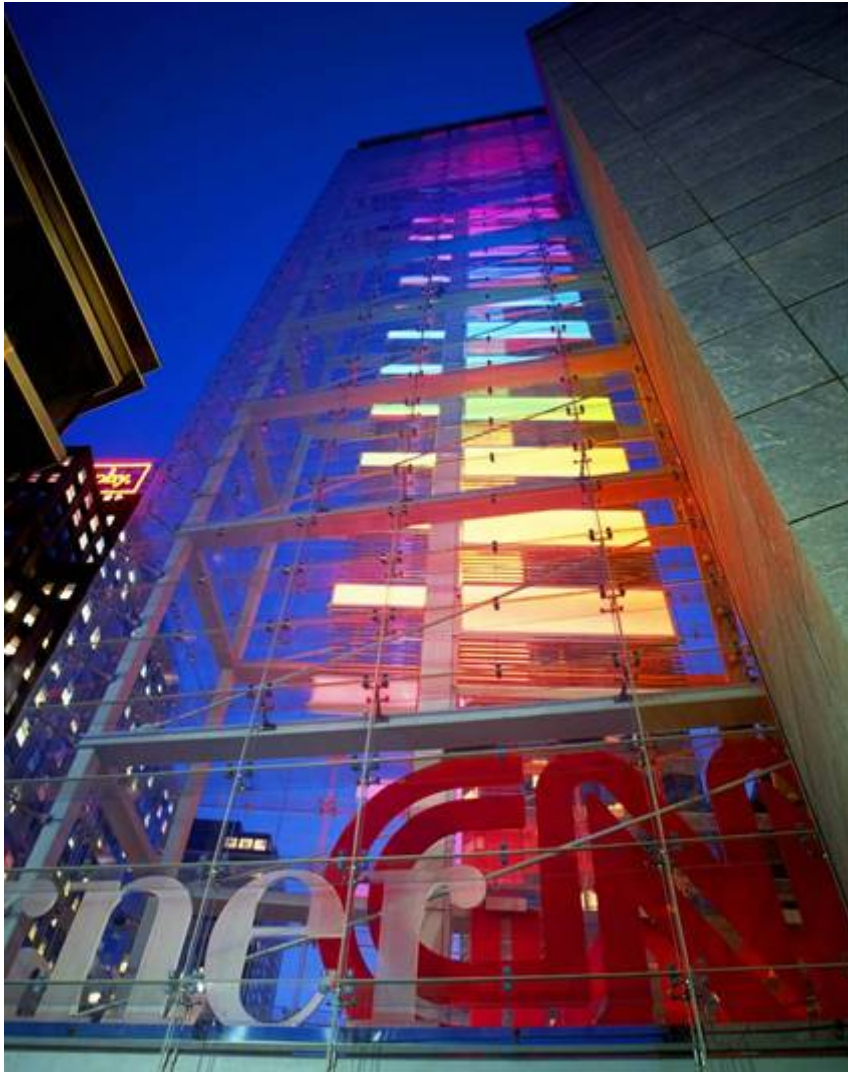


# Crown Fountain at Millennium Park

Chicago, IL



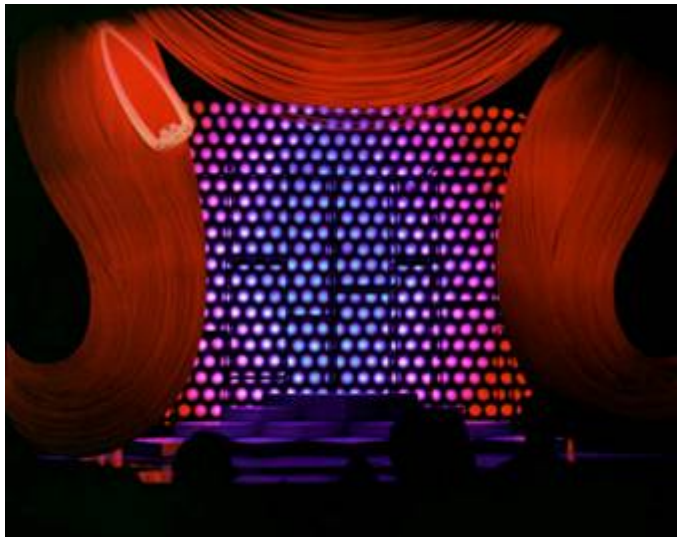
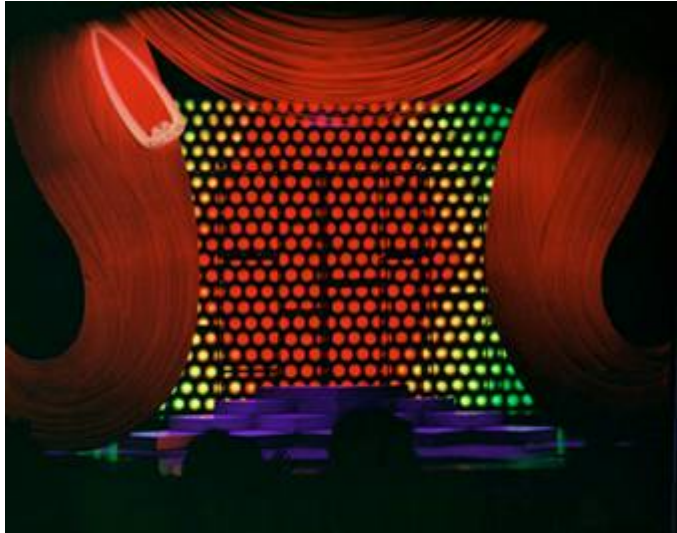
# Prow Sculpture at Time Warner Center New York, NY



Theatrical

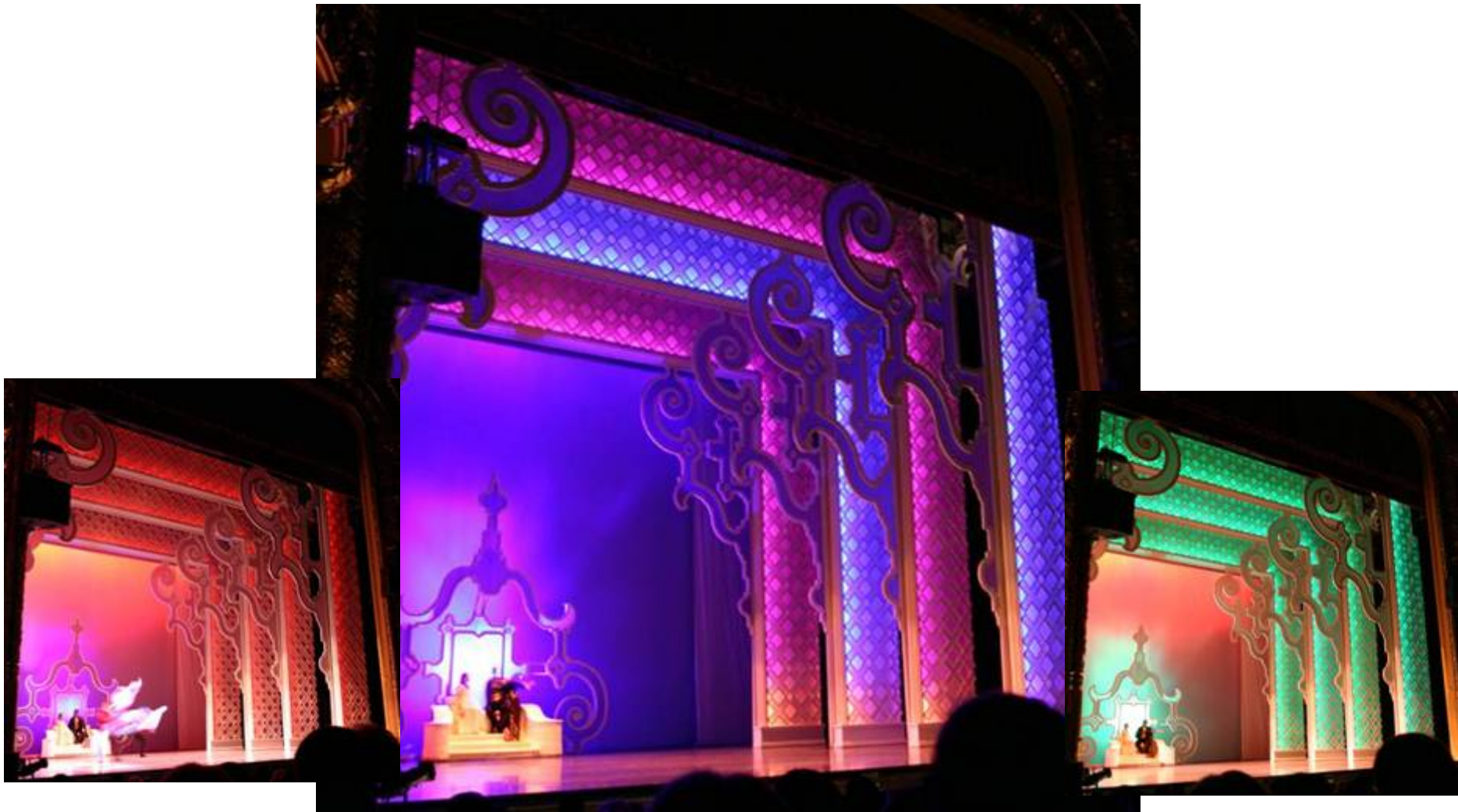
# Hairspray on Broadway

New York, NY



# Boston Ballet – The Nutcracker

Boston, MA



Interior Architectural

# Rustic Kitchen

Boston, MA



# Bostonian

Boston, MA



# Sun Microsystems

Boston, MA



Architectural

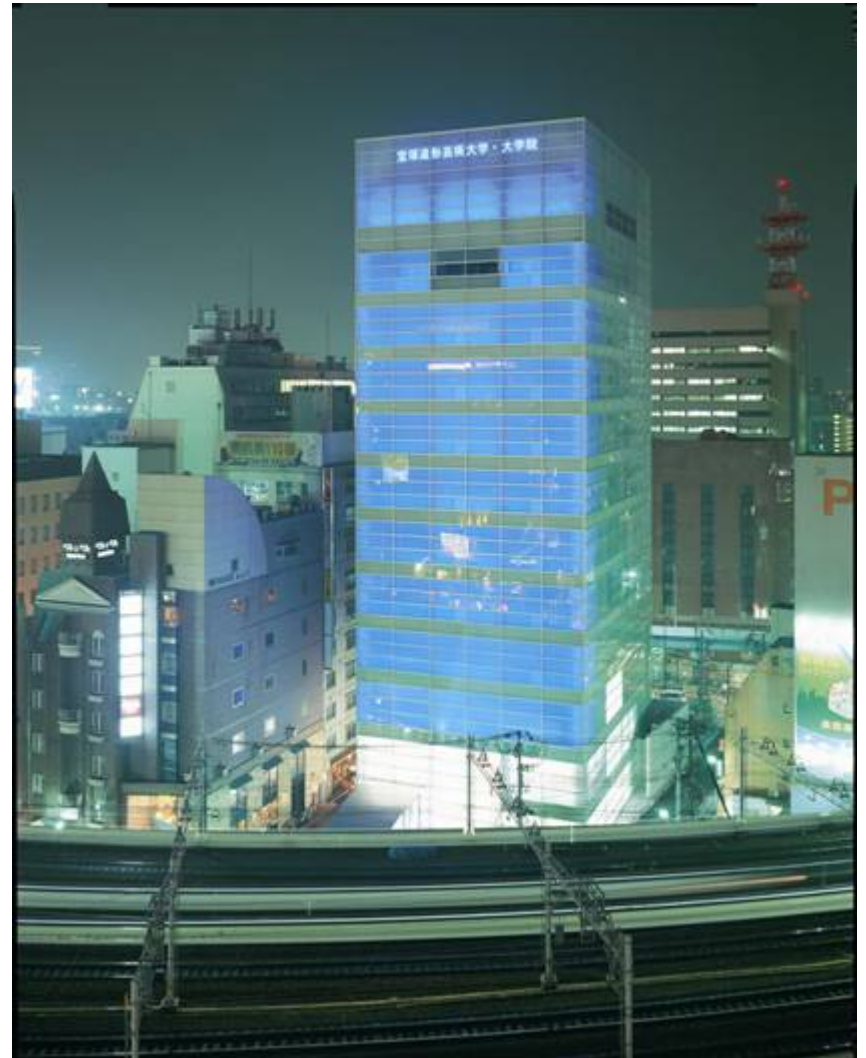
# Hard Rock Hotel

Las Vegas, NV

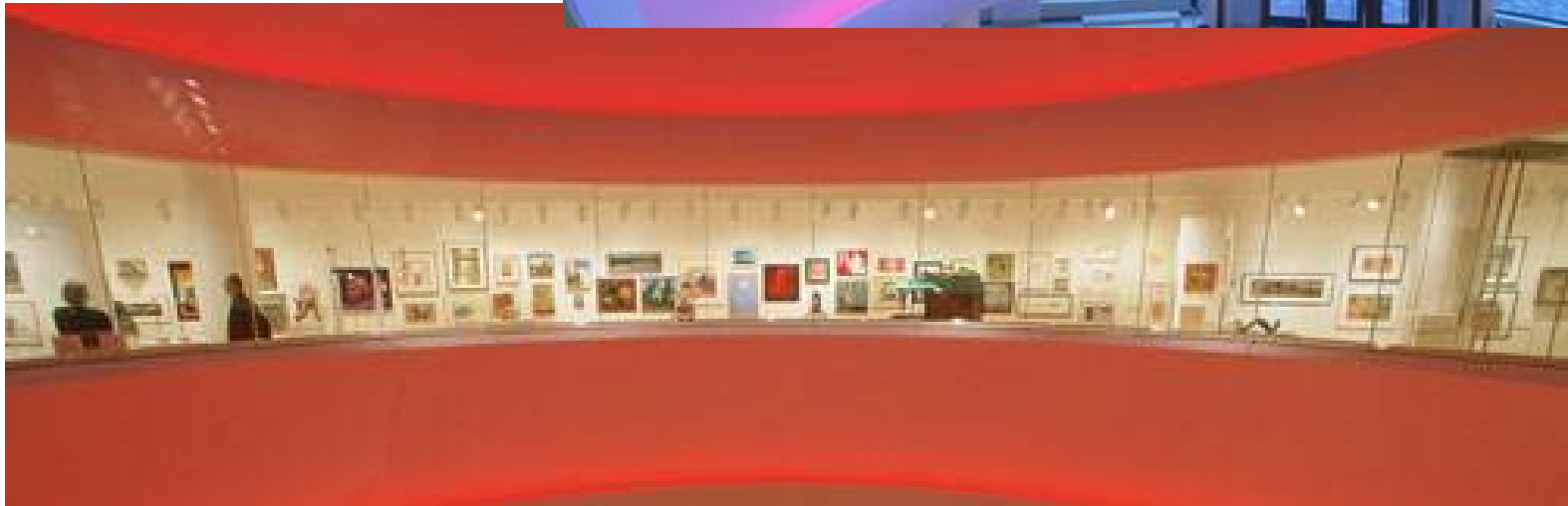


# Takarazuka University of Art and Design

Osaka, Japan



# Overture Center for the Arts Madison, WI



# Goodman Theatre

Chicago, IL



# New World Centre

Kowloon, Hong Kong



# Yoshikawa Building

Aoyama, Tokyo, Japan



# Harrah's Atlantic City Resort & Casino Atlantic City, NJ



# South Beach Shops

Miami, FL



# Caisse des Depots et Consignations

Paris, France



# Other Applications

# Benjamin Franklin Bridge

Philadelphia, PA



# Wheel of Fortune

Los Angeles, CA (Sony Pictures Television)



# Carnival Valor



# Nintendo, E3 2004

Los Angeles, CA



# Ponca City Memorial Fountain

Ponca City, OK



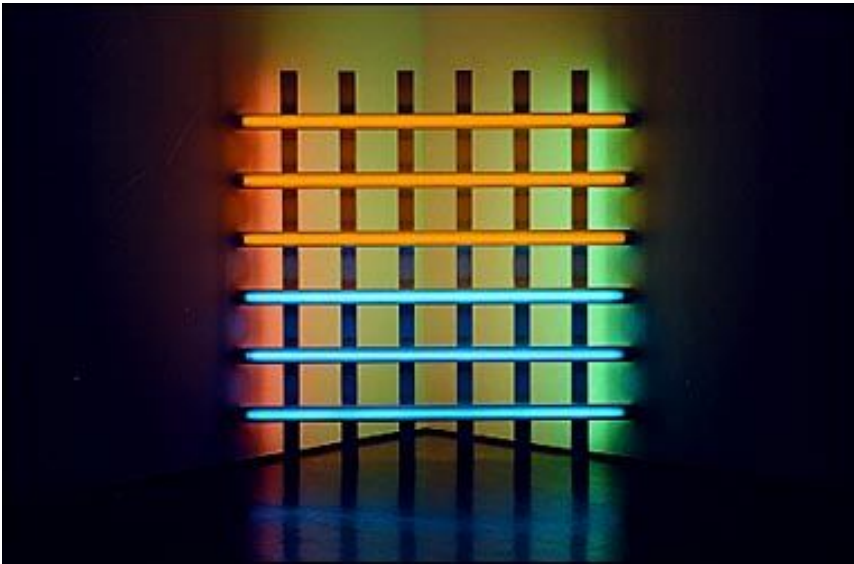
# La Cittadella

Kawasaki, Japan



# Reinventing Light: A New Medium

- From Flavin to Turrell and Villareal
- Fluorescents to LEDs

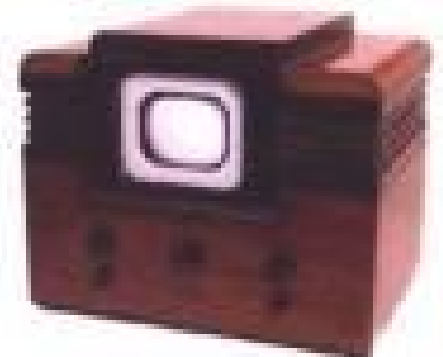


*Light as art evolves*  
*LEDs are integral*



# A New Medium

- New mediums imitate predecessors
  - Early movies = films of stage plays
  - Early TV = radio with pictures
- Every medium needs time to form its own form and vocabulary
- LED lighting will do the same
- LED lighting is not simply a replacement technology. This approach weakens its capability



# Easy Predictions

- Solid-state sources are changing the face of lighting
  - All colored light is in transition
  - Performance increases
  - Costs decrease
- Now white LEDs



# Hard Predictions

- What is fixture or lamp?
- Fixture gives way to form
- Integrate into structures, furniture, accessories
- The *illuminated* becomes *illuminating*
- What happens when
  - A 1000 lumen source is the size of a quarter
  - Uses only 10W of energy
  - Costs of a few dollars
- We do not understand the impact



*“Grandpa, what is this picture?”*

*What happens when the  
incandescent source  
disappears?*

*We predict the icon  
will outlive the lamp*



Thank you!

